

A Path to N+3 Fuel-Flexible Combustors



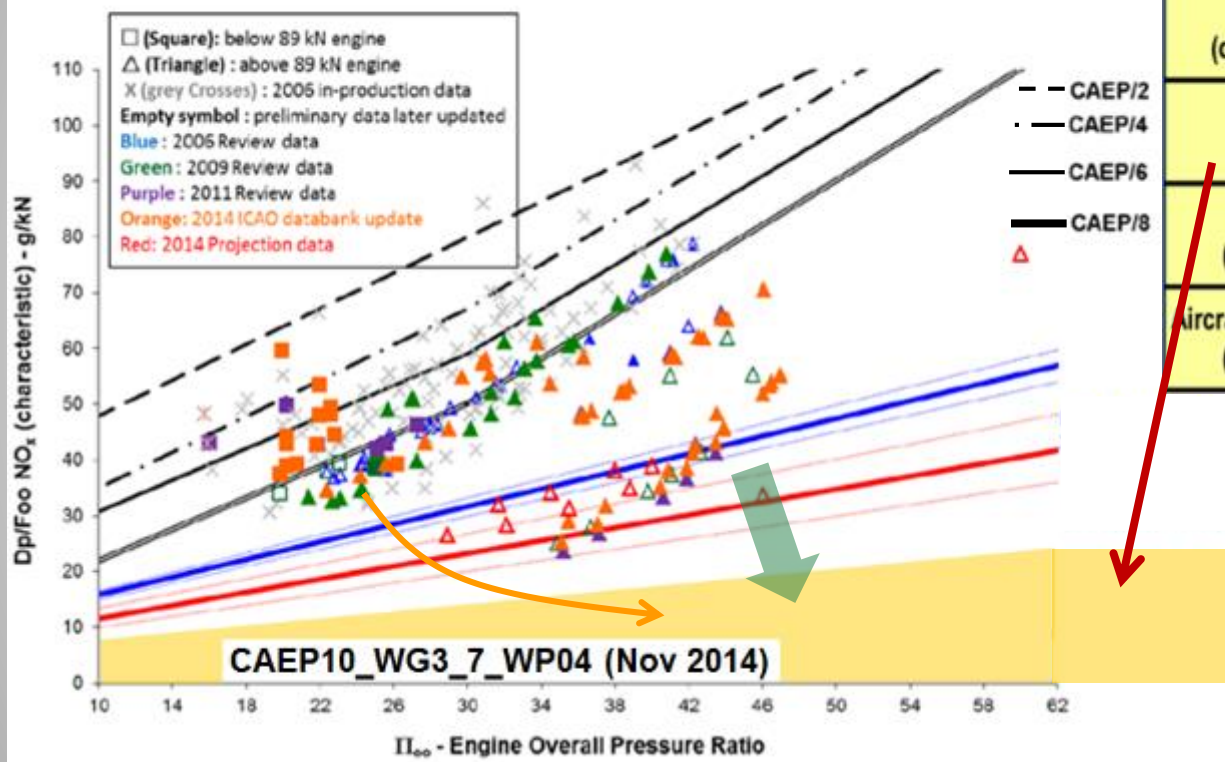
Angela Surgenor
NASA Glenn Research Center
Green Aviation Technical Information Meeting
March 31, 2016

Technological Challenges for N+3 Small Core, Fuel-Flexible Combustors



Need to overcome trend for NO_x to increase with OPR ↑

Recent/Near Term Engine, Previous Review and 2014 In-Production Certification Data



TECHNOLOGY BENEFITS*	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-52 dB
LTO NO _x Emissions (rel. to CAEP 6)	-80%
Cruise NO _x Emissions (rel. to 2005 best in class)	-80%
Aircraft Fuel/Energy Consumption [†] (rel. to 2005 best in class)	-60%

Need to support high efficiency goal: - high OPR
- high BPR (small core)

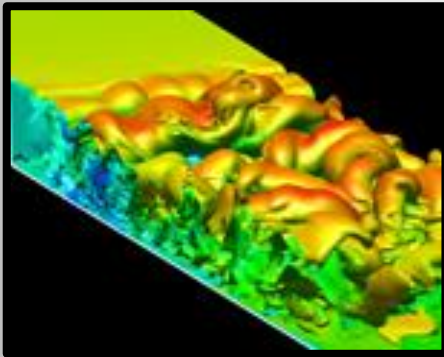


N+3 Small Core, Fuel - Flexible Combustor

Multiple Project's Support

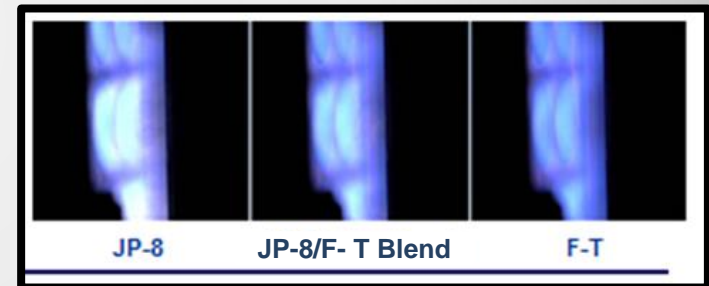
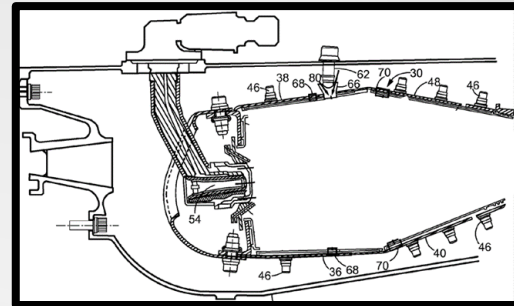


Transformative Tools and Technologies (TTT) Project



Objective : Develop and validate physics based combustion models, perform fundamental experiments and investigate new combustor technologies.
(TRL 2- TRL 5)

Advanced Air Transport Technology (AATT) Project



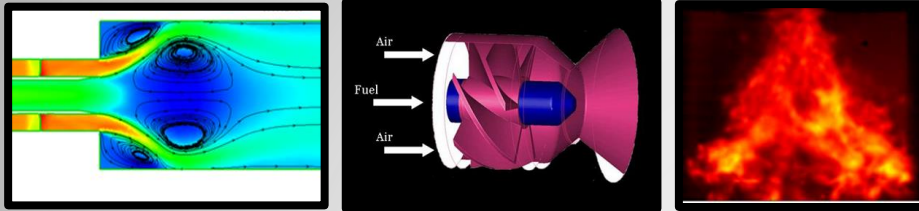
Objective : Reduce NOx emissions from small core , fuel-flexible combustors to 80% below the CAEP6 standard with minimal impacts on weight, noise, or component life.
(TRL 3 – TRL 6)

N+3 Small Core, Fuel - Flexible Combustor

Multiple Project's Scope

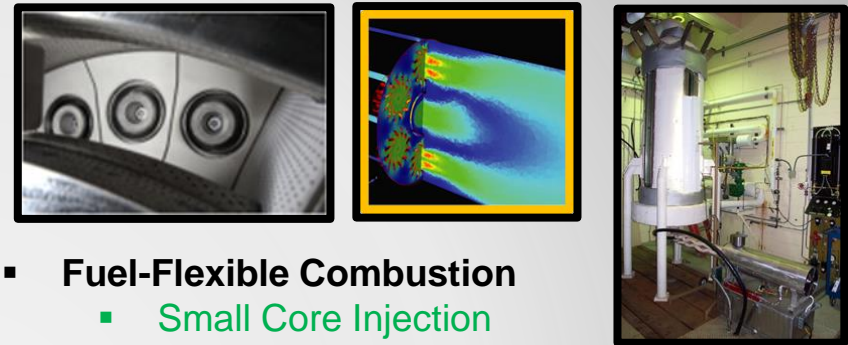


Transformative Tools and Technologies (TTT) Project



- **Develop/Validate Critical Computational Tools**
 - Physics-based CFD combustion models
 - Combustor-Turbine Interactions
 - Validation experiments
- **Develop/Test Critical Combustion Technologies**
 - Lean Direction Injection (LDI)
 - Staging Technologies
 - Combustion Dynamics Mitigation/Control
- **Explore/Evaluate Innovative Combustion Technologies/Concepts**
 - Pressure Gain Combustion Concepts

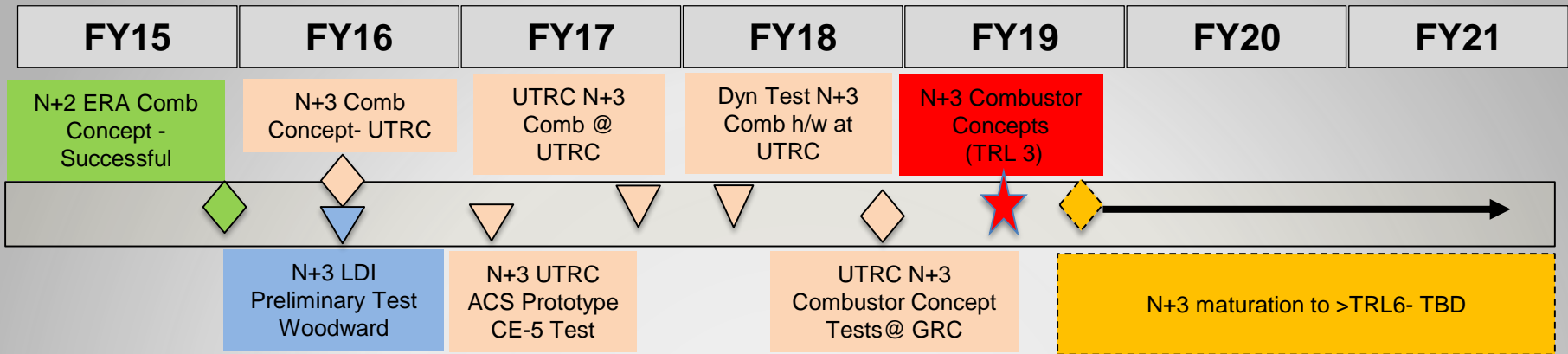
Advanced Air Transport Technology (AATT) Project



- **Fuel-Flexible Combustion**
 - Small Core Injection
 - Combustor Stability
 - Durability
 - Performance
- **Alternative fuel performance**
 - Thermal stability
 - Emissions
 - Lean blowout / ignition
 - Auto-Ignition / Flashback
 - Low aromatic effects
- **Particulate Matter Emissions**
 - PM emissions at ground and cruise altitudes extracted from combustor only

Technical Challenge 4.1

Low NOx, Fuel-Flex Combustor CAEP/6 -80%, TRL 3



AATT: Fuel-Flexible Combustor

- Explore/develop combustor concepts through flame tube tests
- Evaluate combustor dynamics & staging characteristics for N+3 high power-density operations
- Apply combustor system dynamics mitigation & active control technologies from TTT
- Evaluate impacts of alternative-fuels and blends on combustion and fuel systems in laboratory

TTT (TAC)

- High temperature CMC liners
- High-pressure spray validation data
- LDI fundamentals
- Closed-loop active combustor control strategy
- Combustion flow physics, fuel composition effects, and gaseous/particulate emissions
- Active combustion control

Other Research Theme Investments

- *Particulate Matter Emissions*

CST: High Altitude Emissions

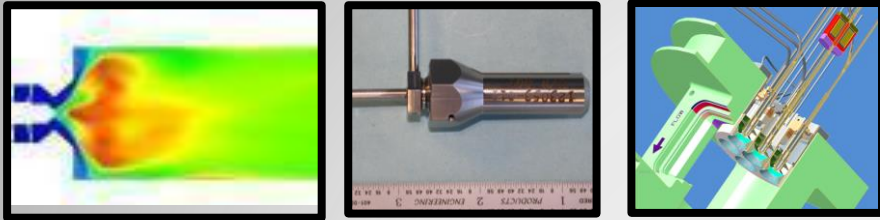
- Assess/adapt high-pressure comb designs from AATT for supersonic cruise conditions

N+3 Small Core, Fuel- Flexible Combustor

In-House/ Partnership and Collaboration Efforts



Transformative Tools and Technologies (TTT) Project



- **Develop reduced kinetics and turbulent combustion models sensitive to fuel composition and property changes**
 - Emerging Technical Challenge for TTT
 - TTT NRAs* supporting NJFCP
 - Stanford & Uconn → reduced kinetics
 - Stanford & Georgia Tech → turb/comb models
 - Operability (LBO, Ignition)
 - NOx and Soot Mechanisms
- **In- House Research**
 - Active Combustion control / Fuel Modulation with 7-point LDI
 - Staging/ LDI Pilot Strategies
- **National Jet Fuels Combustion Program**
 - Alternative fuel testing of 9-pt LDI in CE-5
 - OpenNCC simulations of AFRL Referee Rig

Advanced Air Transport Technology (AATT) Project

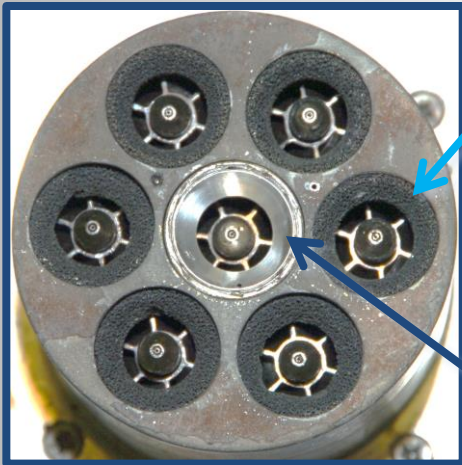


- **Fuel Flexible Combustor for High-OPR, Compact-Core N+3 Propulsion Engine**
 - UTRC NRA* Award
 - Space Act Agreement with Woodward FST
 - In-house 9-point LDI Injector
 - Systems Analysis Team (GRC) & Georgia Tech
- **Alternative Fuels/ Particulates**
 - National Jet Fuels Combustion Program (NJFCP) Alternative Fuels Combustion Tests
 - Space Act Agreement with FAA to support standardization of Particulate Measurement System

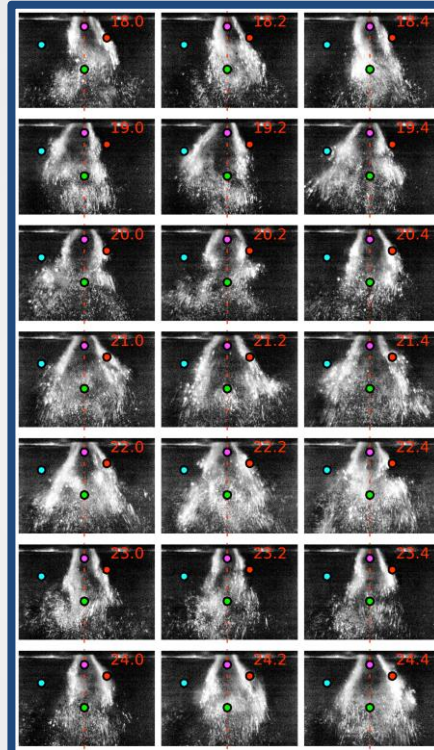
* NRA – NASA Research Announcement

CE-13C Combustion & Dynamics Facility

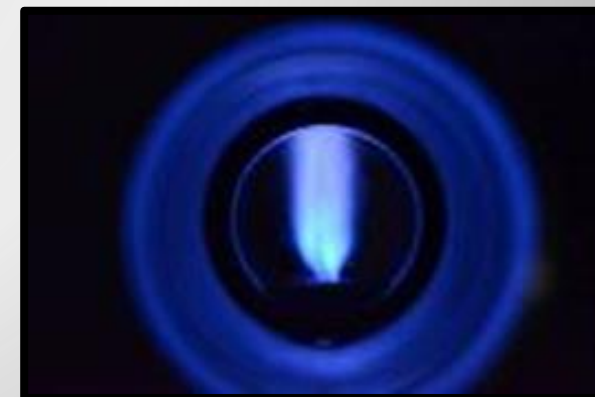
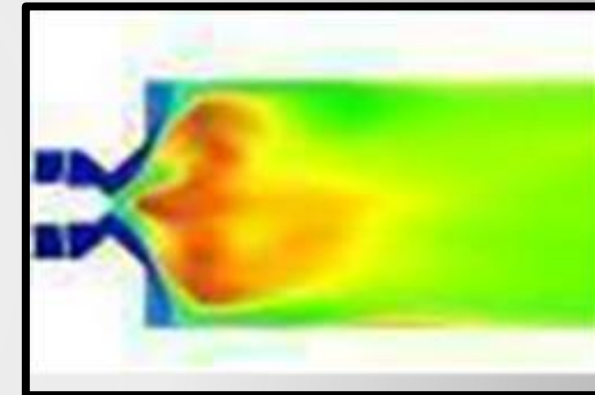
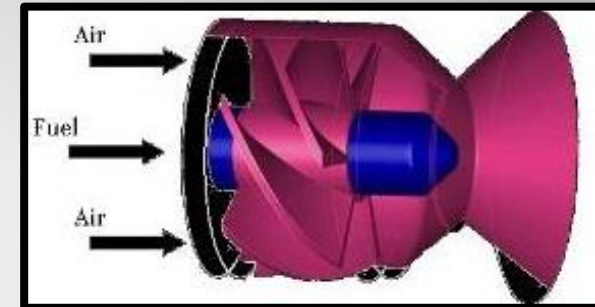
7-point, damping
venturis



Mixing Studies



Single fuel/air mixer



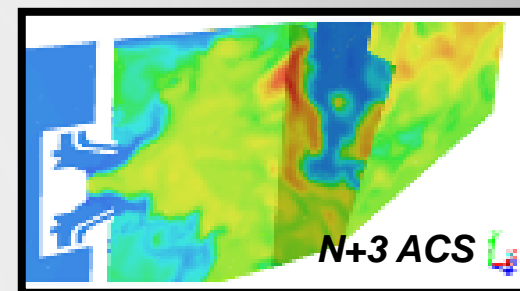
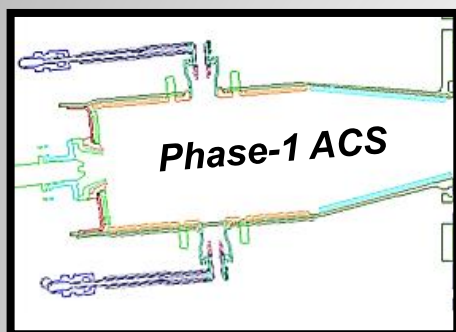
In-House Fundamental Combustion Research

NASA Research Announcement (NRA)

Small Core N+3 Combustor Development with UTRC/ P&W



Further developing P&W's ACS Combustor Concept to meet aggressive N+3 emissions goals, w/ scalability

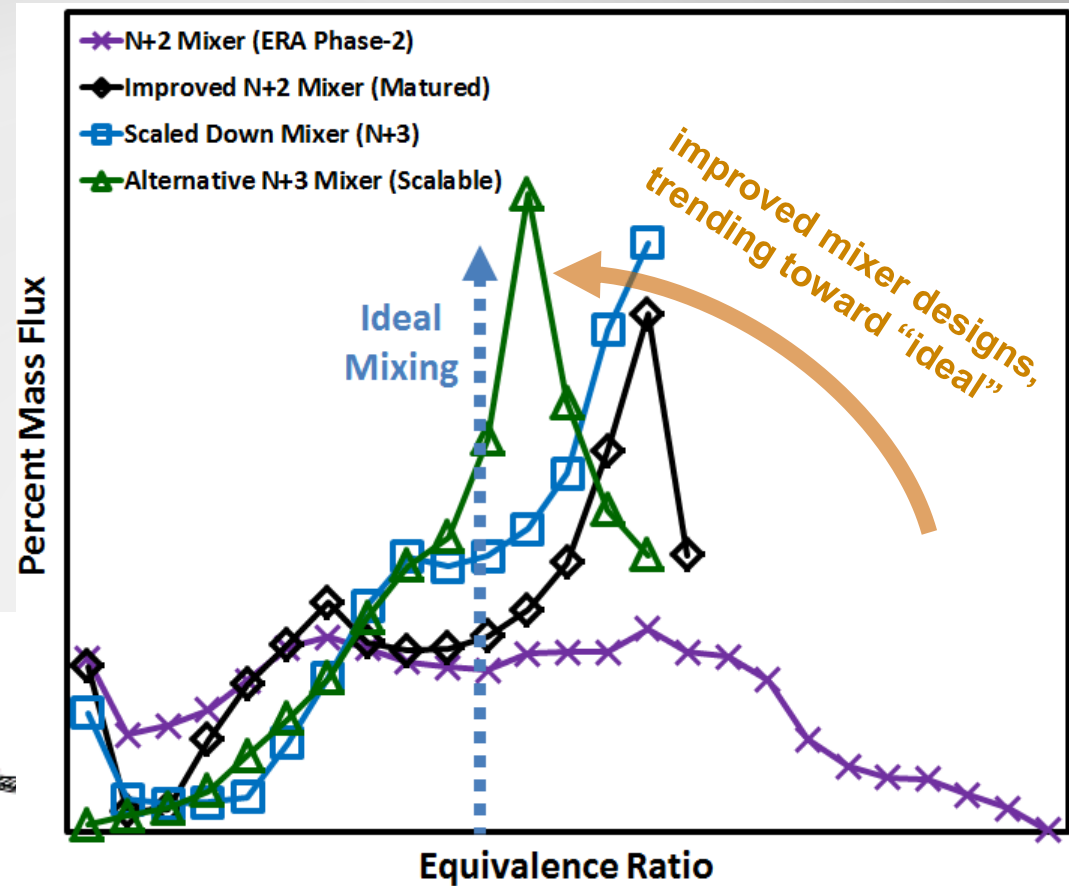


Combustor Feature	Phase-1 ACS Combustor	Phase-2 ACS Combustor (N+2)	N+3 ACS Combustor
Combustor Size & Config.	Unconstrained	Fits within existing GTF engine	Scale down for N+3
LTO NOx (%below CAEP6)	–88% @ NASA ASCR	–81% in full annular comb. tests	>80% margin
Cruise NOx (%below 2005)	–80-90% (EINOx basis)	–68% (EINOx basis, vs. PW4098)	>80% margin

Fuel injectors / mixers critical to meeting N+3 emissions goals

Developing main mixers that:

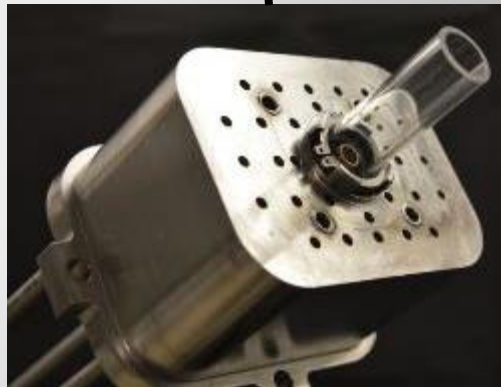
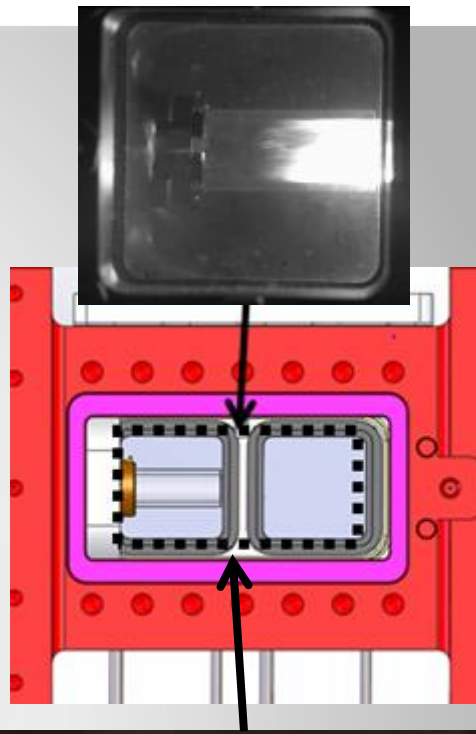
- Meet auto-ignition and flashback criteria, for robust operation
- Approach “ideal” mixing for a wide range of operating conditions
- Are scalable to a range of engine core-sizes (N+2, N+3...)



Alternative Fuel Investigations

Evaluating ACS technology for use with alternative fuels

	Fuel	POSF	ASCENT Designation	Selection Rationale	Performance Impact
1	Jet-A	10325	A-2	Baseline Properties	Baseline Performance
2	Gevo	11498	C-1	Low Cetane #	Longer ignition delay, loss of LBO margin
3	JP-5 (64v%)/Farnesane(36v%)	12341	C-3	High Viscosity/High Surface Tension	Droplet SMD Increase, slower fuel air mixing
4	iso-C10s (73v%)/trimethylbenzene(27v%)	12345	C-5	Flat distillation curve; Low Boiling Pt.	Faster vaporization, fuel-air mixing, pre-ignition
5	Rentech	7898	-	High Cetane #	Shorter ignition delay, pre-ignition, mixer length impact



Evaluating auto-ignition for 4 alternative fuels & Jet-A:

- Fuels obtained from AFRL (NJFCP) & NASA
- Tests performed up to 800 psia, 1300 F inlet conditions
- Measuring auto-ignition location / time downstream of ACS mixer

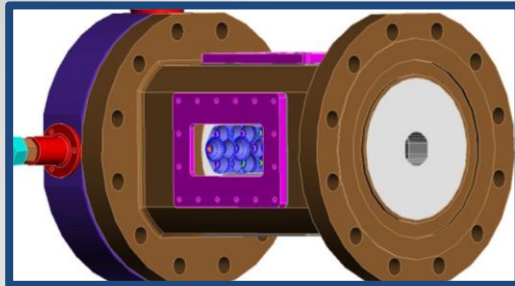
Space Act Agreement (SAA)

Woodward, FST

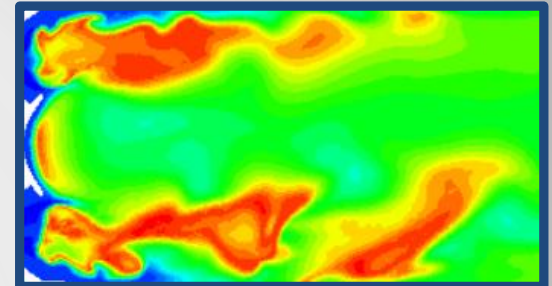


Objective: Develop a lean direct injection (LDI) concept for a small-core N+3 engine what will reduce NOx emissions by 80% wrt CAEP/6.

Small Core N+3
SV-LDI 3-cup
hardware in
flame-tube
(TRL 3)



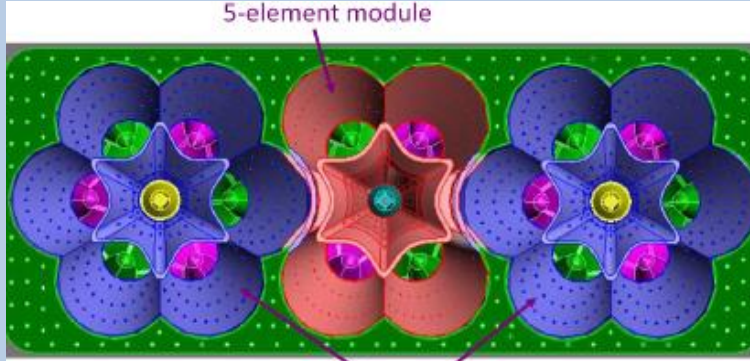
Recent CFD
Flame
Temperature
Results



Small Core N+3 SV-LDI

N+3 Dome, Three Cups

5-element module



7-element module

N+3 Fuel Stem

Main injection X 6

Pilot injection



Space Act Agreement (SAA)

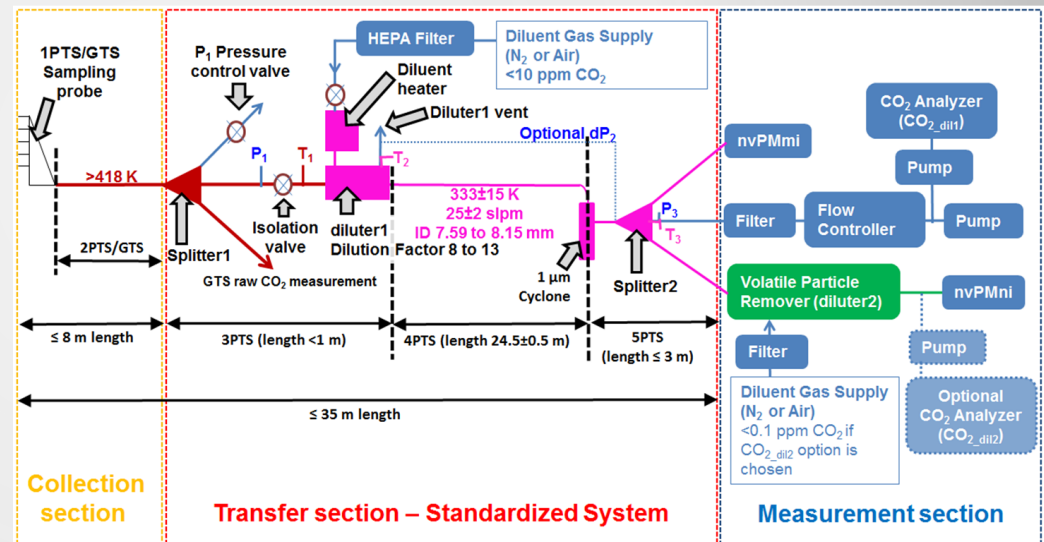
FAA- Aerosols and Particulate Measurements

Objective: Develop, validate and verify the operation of the FAA's AIR6241 Particulate Measurement system with NASA GRC's High pressure Flame- Tube Combustor Test Facility.



New Mobile Particulates Measurement System at GRC

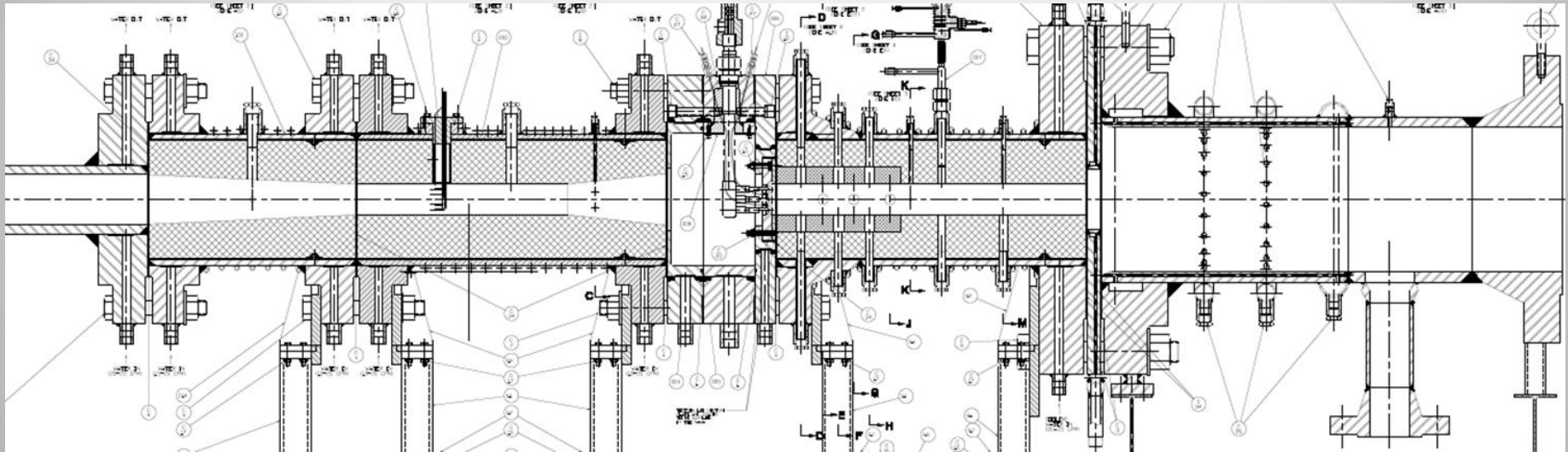
Components of an AIR6241 System



Advanced Subsonic Test Facility

New High Pressure Flame-Tube Design

	CE-5		ASCR
	Stand 1	Stand 2	Stand 2
Inlet Air Pressure Supply	450	450	1100
Combustor inlet Air Pressure P3 (PSI)	275	450	900
Inlet Airflow (PPS)	0.9 – 12	0.5 – 5	0.25 – 14
Combustor Inlet Air Temperature (F)	1200 (rated for 1350)	1100	1300
Fuel Supply Pressure (PSI)	900	900	2000



***Detailed Design ~75% Complete**

****Facility readiness dependent on funding, but could be as early as FY19**

Summary

